Russian Journal of Aquatic Ecology, 2(2), 1993, pp. 103-109

BACTERIOPLANKTON OF SURFACE WATERS IN ANTARCTIC ZONE OF THE PACIFIC

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ABSTRACT. Based on data on bacterioplankton concentration and hydrophysical characteristics in the surface zone of transect along 67°S latitude in the Pacific sector of the Antarctic, the boundaries of main habitats of microplanktonic organisms are defined for that part of the South Ocean. The role of bacteria and «microbial loop» in the functioning of pelagic complexes in studied waters is discussed. The material was collected at 21 stations in the 0-200 m layer from February 22 to March 30, 1992. During the period of works, the density of bacterioplankton varied from $68 \cdot 10^3$ to $634 \cdot 10^3$ cells/mL, the mean volume of bacterial cells fluctuated within the range of 0.042-0.170 μm^3, and the biomass changed from 9 to 82 mg/m^3. The data on the number and biomass of bacteria show that in the region studied, the microplankton complexes are vertically restricted by waters of summer warmed and cold residual layers. The highest gradient of mean cell volumes and, to a lesser extent, of bacterial abundance was associated with 0° isotherm at the lower border of cold residual layer. Two large habitats are clearly distinguished horizontally: the waters of southern periphery of Antarctic Circumpolar Current and the waters of the Ross circulation separated from the former by a transition zone. Relatively high values of bacterial density and biomass obtained by the author indicate that, even in the most southern part of open areas of the South Ocean Antarctic zone, the microorganisms intensively recycle the nutrients, i.e. a considerable flux of matter and energy passes through the microplanktonic community.

Key words: Pacific sector of the South Ocean, bacterioplankton distribution; abundance, mean size, and biomass of bacteria.

Introduction

Traditional views on the organization of food web in the South Ocean pelagial have recently been subjected to serious changes (Hewes et al. 1985, Smith and Nelson 1986, Azam et al. 1991). The well-known idea about simple trophic chain consisting of large diatom algae, krill and whales (seals, birds) appeared in the period of intense exploration of South Ocean to explain exceptional abundance of vertebrate animals and birds in Antarctic waters. However, subsequent studies have shown that the bulk of phytoplankton (by biomass, chlorophyll *a*, and primary production) in the Antarctica is formed by small (less than 20 μm,) pico- and nanoplanktonic algae (Brokel 1981, Hewes et al. 1985, Weber and El-Sayed 1987, Rat'kova 1987). Admittedly, the Antarctic waters, despite their high concentrations of nutrients, may be assigned to oligotrophic or transitional from oligotrophic to mesotrophic ones by the level of primary production (100-300 mgC/m^2 per day) in the period of phytoplankton growth (Holm-Hansen et al. 1977, Brokel 1981, El-Sayed and Taguchi 1981, Azam et al. 1991, etc.).

Characteristic of the South Ocean low primary production created mainly by small nanoplanktonic forms suggest that a considerable and sometimes principal flux of matter and energy passes through the microplankton and remains within the microplanktonic community (the so-called «microbial loop»). This suggestion is confirmed by numerous measurements of microorganism concentration and rates of bacterial growth and production in the Antarctica. The values obtained are no less than in temperate and tropical waters (Fuhrman and Azam 1980, Azam et al. 1981, Hodson et al. 1981, Hanson et al. 1983, Kogure et al. 1985, Delille et al. 1988, Putt et al. 1990, Rivkin 1991, etc.). Thus the organization of pelagic food web in the South Ocean is based on the microplankton community where the most part of organic matter is transformed (Azam et al. 1991).

The distribution of bacterioplankton is strictly dependent on some physical parameters which determine properties and borders of their specific

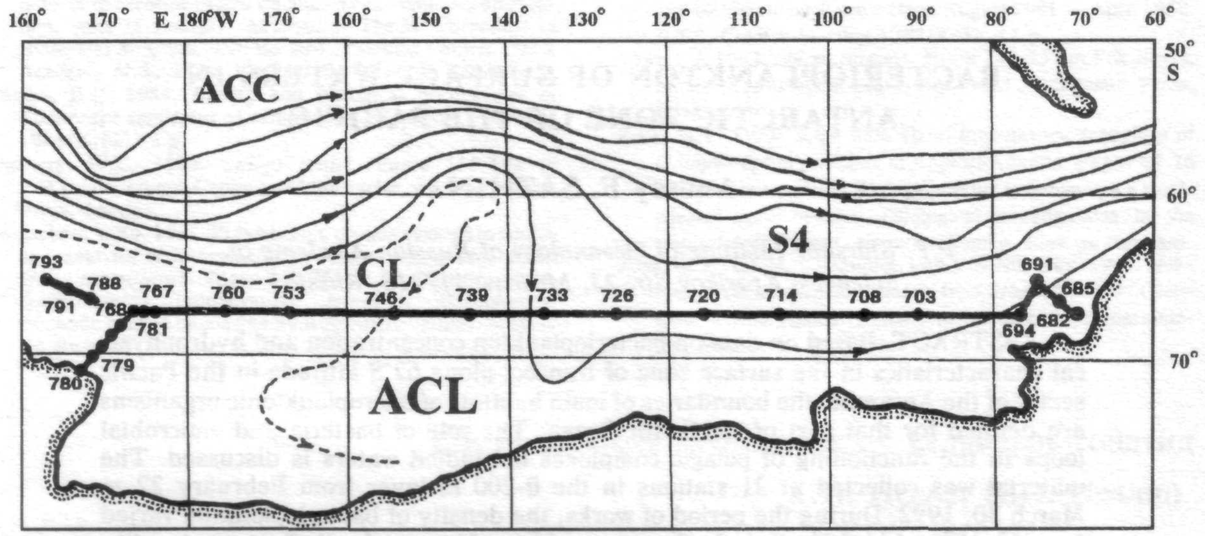


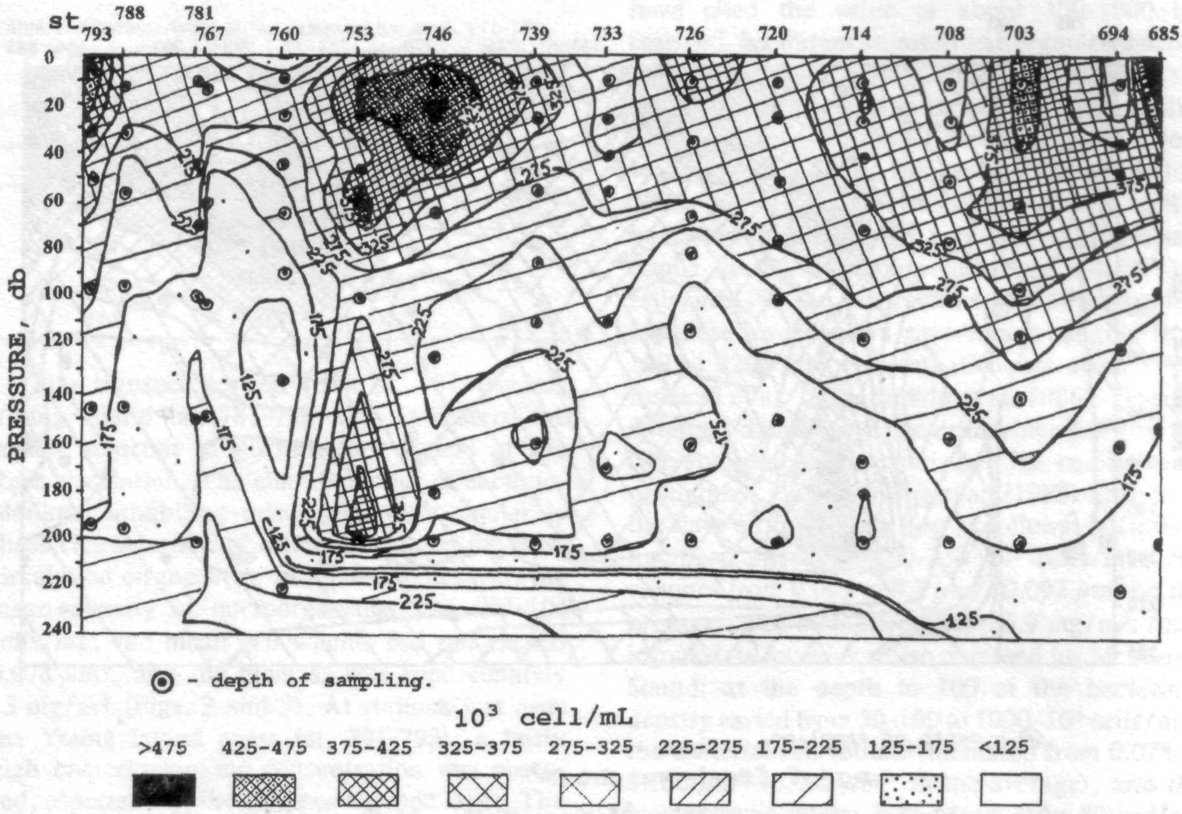
Fig. 1. Scheme of the area of studies and the position of stations along the S4 transect. ACC — Antarctic Circumpolar Current CL — cyclonic Ross loop, ACL — anticyclonic Ross loop.

habitats. The pecularities of microorganism distribution, in its turn, facilitate the identification of water masses. It allows to get a more comprehensive view of circulation pattern and reveal homogeneous (by hydrophysical characteristics) environments which serve as habitats for pelagic communities.

The present paper is devoted to precisely these questions. Simultaneous consideration of hydrophysical data and bacterioplankton structure characters more clearly reveals the boundaries of main habitats of pelagic complexes. Analysis of distribution of bacterioplankton abundance, biomass, and mean cell volumes in the Pacific sector of the Antarctica provides better understanding of «microbial loop» functioning in that part of the South Ocean.

Material and methods

The material was collected at 21 stations of trans-Antarctic transect (S4) along 67°S latitude (Fig. 1) from February 22 to March 30, 1992 during the 6th cruise of R/V «Akademik Joffe» within the frameworks of the International Project WOCE (World Ocean Circulation Experiment). The ship moved from east to west and crossed several water types. The works have been started in the narrow zone of slope front of the Antarctic Peninsula (72°W, st. 685) where there is no direct water exchange between Antarctic Circumpolar Current (ACC) and the shelf. Most of the stations were situated at the ACC southern periphery (75°-133°W, st. 694-726), then the transect crossed the transition zone between waters of ACC and Ross cyclonic circulation (133°-145°W, st. 733) and passed along the southern part of the Ross circulation itself (140°-166°W, st. 739-753). This circulation system is connected with a spread of mixed waters, including both waters of the ACC southern periphery and waters of high latitude modification, over a large area. In the western part of studied region, the transect continued southwestwards to the Pennell Coast (st. 767-779), then the works were carried out from the turning point (st. 767) to northwest of Young Island (Balleny Islands) (st. 781-793, Fig. 1). Waters of Balleny dynamic systems comprise a part of mainly cyclonic island circulation and are somewhat insulated from the Ross circulation (Maslennikov 1992). The works performed along the transect involved sonde exploration of the whole mass of water to the bottom and sampling for hydrochemical and biological analyses. For the water sampling, a system was used which consisted of 24 polychlorvinyl 10-liter samplers and was combined with a CTD-profiler Mark III (Neil Brown Instruments System, NBIS) modified in the Datum Collection Department of the Scripps Institution (USA). Samples were usually collected at 8 horizons of the upper 200-m layer, i.e. in the surface water mass including the summer warmed layer and the cold residual layer with minimum temperatures (Maslennikov 1992). The selection of horizons was determined by a preliminary analysis of distribution of the water density and temperature. The bacterial abundance was assessed by direct counting on nuclear lavsan filters with pore diameter of 0.17 μm (production of Dubna city, Russia). The filters were pre-stained with sudan black «B» and studied with luminescence micro-



Figs. 2. Distribution of bacteria abundance along the S4 transect.

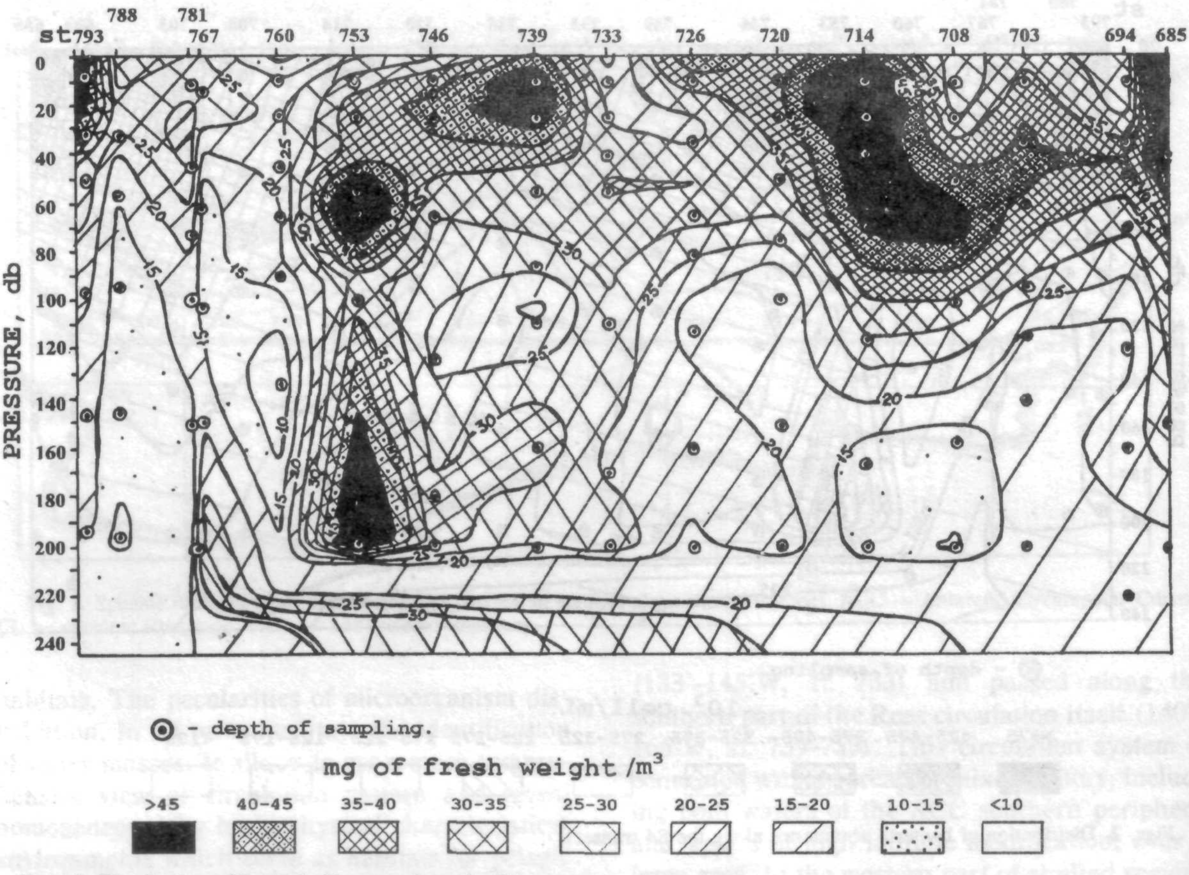
scope LUMAM-I2 at x1250-2000 magnification. Bacteria were stained with acridin orange fluorochrom (Hobbie et al. 1977). The filtered sample volume was 10-20 mL. Bacteria were counted in 10-20 fields of vision. Standard deviation comprised 10-20% of the counted cell number. Bacteria were measured with ocular ruler at x2000 magnification. A total of about 50 cells was measured from each horizon. In the case of 3-5 times variation in linear cell size, up to 100 bacteria were measured. The volume of cocci was calculated by the sphere volume formula, that of bacilli — by the cylinder volume formula. The biomass of bacterioplankton was estimated from the number and mean cell volumes.

Results

The density of bacteria in waters studied varied from $68 \cdot 10^3$ cells/mL to $634 \cdot 10^3$ cells/mL (Fig. 2). The mean cell volume of bacterial cells varied within 0.042-0.170 μm^3 range, the biomass changed from 9 mg of fresh weight per 1 m^3 to 82 mg/m^3 (Fig. 3). The highest concentrations of microorganisms were associated with the summer warmed layer 30-80 m thick. The maximum of the bacterioplankton numbers and biomass usually fell on the lower part of summer warmed layer. In underlying cold residual layer, whose lower boundary as a rule was at the depth of 190 m, the density of bacteria decreased by 1.5-2 times. The distribution of microorganism biomass generally was the same as that of their numbers.

The highest values of the abundance, mean volumes and biomass of bacteria were recorded in the zone of slope front of the Antarctic Peninsula (st. 685) which is characteristic of frontal zones (Sazhin and Kopylov 1988). The density of microorganisms ranged from 445 to $634 \cdot 10^3$ cells/mL in the summer warmed layer at st. 685; it drastically decreased in the deeper layer, and therefore the mean bacterium concentration in the upper 200 m layer did not exceed $304 \cdot 10^3$ cells/mL during the period of our studies. Large forms prevailed among the microorganisms. In summer warmed and cold residual layers, the volume of bacterial cells varied from 0.128 to 0.170 μm^3 with the mean value 0.138 mm^3. The highest values of bacterial biomass (57-82 mg/m^3) were also characteristic of waters of the Antarctic Peninsula slope front, the mean value in the 0-200 m layer was 42 mg/m^3 during the period of studies.

The microorganism concentration decreased in waters of the ACC southern periphery (st. 694-726) as compared to waters of the Antarctic Peninsula frontal zone. The mean abundance of



Figs. 3. Distribution of bacteria biomass along the S4 transect.

bacteria in the surface 200 m layer was $264 \cdot 10^3$ cells/mL, insignificantly varying ($230\text{-}336 \cdot 10^3$ cells/mL) with each station. Fluctuations of the mean cell volumes and the biomass of bacteria were also minor in the ACC waters (0.082-0.133 μm^3 and 25-36 mg/m^3 respectively). The mean volume of bacteria in this part of the transect was 0.107 μm^3 during the period of studies while the mean biomass was 28 mg/m^3.

In the transition zone (st. 733), the concentration of bacteria was even lower in comparison with both ACC and Ross circulation waters (Figs. 2 and 3). The numbers of microorganisms were there $161\text{-}294 \cdot 10^3$ cells/mL (on the average, $230 \cdot 10^3$ cells/mL in the 0-200 m layer). The volume of bacterial cells exceeded that in the ACC waters achieving a mean of 0.125 μm^3 on the average. Due to the predominance of large forms the biomass of bacterioplankton in the transition zone waters practically did not differ from the mean bacterium biomass in the ACC waters achieving 28.7 mg/m^3.

Waters of the Ross circulation itself (st. 739-753) were characterized by an increased numbers of bacteria in both summer warmed layer ($261\text{-}482 \cdot 10^3$ cells/mL) and cold residual layer ($188\text{-}425 \cdot 10^3$ cells/mL), the latter being thinner than in the ACC waters (Figs. 2 and 3). The mean volume of bacterial cells varied from 0.065 to 0.147 μm^3 (0.114 μm^3 on the average), the biomass ranged from 19 to 64 mg/m^3 (with the mean 35 mg/m^3 for the Ross circulation waters). The largest microorganisms were characteristic of waters at the border between summer warmed and cold residual layers.

The area adjacent to the western boundary of the Ross circulation (st. 760, 767, 781) was greatly depleted in bacterioplankton. The bacterioplankton density in the 0-200 m layer was in the range $162\text{-}221 \cdot 10^3$ cells/mL at different stations, the biomass being 16-22 mg/m^3 (Figs. 2, 3). Small cells prevailed in the bacterioplankton, their mean size ranged from 0.093 to 0.106 μm^3 in the surface 0-200 m layer.

At the transect portion from st. 767 towards the Pennell Coast (st. 771-779, Fig. 1), a gradual decrease was observed in the bacterial abundance from open waters to coastal ones. The bacterial density in the coastal zone was about twice increased as compared to open waters, the biomass was three times increased. The mean bacterium volume slightly increased approaching to the coast and this tendency could be clearly traced from one station to the next one (Table 1).

Table 1. Characteristics of bacterioplankton at st. 771-779. N is the mean abundance of bacterioplankton in the 0-200 m layer (10^3 cell/mL). V is the mean volume of bacterial cells in the 0-200 m layer (μm^3). B is the mean biomass of bacterioplankton in the 0-200 m layer (mg/m^3).

No. of station	N	V	B
771	192	0.062	12
774	340	0.067	23
776	359	0.063	23
779	368	0.092	34

The transect portion from st. 781 towards Young Island (st. 781-793, Fig. 1) crossed the region adjacent to northeastern waters of the Ross circulation. The characteristics of bacterioplankton inhabiting this region were similar to these characteristic of waters bordering the Ross circulation on the west. In the 0-200 m layer, the mean density of microorganisms was $199 \cdot 10^3$ cells/mL, the mean cell volume did not exceed 0.078 μm^3, and the biomass was approximately 15 mg/m^3 (Figs. 2 and 3). At stations just near the Young Island coast (st. 791-793), a fairly high bacterioplankton concentration was observed, especially in the summer warmed layer. The microorganism numbers were in the range $317\text{-}495 \cdot 10^3$ cells/mL, and the biomass — 29-55 mg/m^3 (Figs. 2 and 3). The mean bacterium volume in the surface near-island waters was about 0.1 μm^3. Calculation performed for the whole 200-m layer has produced somewhat lower values. The mean abundance of bacterioplankton near Young Island was $283 \cdot 10^3$ cells/mL during the period of studies, the mean bacterium biomass achieved 26 mg/m^3.

Discussion

There are no published data on the bacterioplankton of the southern part of the Antarctic zone of the Pacific. However, for other Antarctic regions the values of numbers and biomass of bacterioplankton measured by analogous methods or by biochemical techniques (Karl and Tien 1991). For example, in Gerlache Strait and McMurdo Sound, the abundance of bacteria varied from $50\text{-}100 \cdot 10^3$ cells/mL to $600\text{-}1000 \cdot 10^3$ cells/mL in October - November and December - January (Putt et al. 1990, Karl and Tien 1991). In surface waters of the Scotia Bay and Weddell Sea, the microorganism density was about $200\text{-}500 \cdot 10^3$ cells/mL in open parts (Azam et al. 1981) and $70\text{-}160 \cdot 10^3$ cells/mL near the ice edge (Kottmeier and Sullivan 1990, Sullivan et al. 1990). In the Drake Passage, the concentration of bacteria of about $400 \cdot 10^3$ cells/mL was recorded (Hanson et al. 1983). Azam et al. (1981) have cited the value of about $100\text{-}1000 \cdot 10^3$ cells/mL for waters adjacent to Kerguelen Islands and Adelie Land. Other authors, assessed the abundance of bacteria in these regions by similar values or those about $50\text{-}100 \cdot 10^3$ cells/mL (Bouvy and Delille 1988, Delille et al. 1988, Delille 1990, Delille and Bouvy 1990). Samyshev (1986) has estimated the mean bacterioplankton abundance in the Commonwealth Bay as $427 \cdot 10^3$ cells/mL. For the Australian sector of Antarctica, Japanese investigators gave values ranging from 100 to $2200 \cdot 10^3$ cells/mL (Kogure et al. 1985, Fukuchi et al. 1986, Simidu et al. 1986). Directly obtained data on the bacterium biomass (by the cell volumes) are scarce due to cumbersome procedures. Only Painting et al. (1985) have cited the data on the Prydz Bay as follows: bacterium numbers about of $200\text{-}350 \cdot 10^3$ cells/mL, cell volumes from 0.007 to 0.2 μm^3 (0.092 μm^3 on the average), and biomass of 39.9-55.9 mg/m^3. Analogous data have been also obtained for McMurdo Sound: at the depth to 100 m the bacterium density varied from 50-100 to $1000 \cdot 10^3$ cells/mL, the bacterial cell volume fluctuated from 0.028 to 0.180 μm^3 (0.080 μm^3 on the average), and the biomass was in the range from 4 to 80 mg/m^3 (Putt et al. 1990). According to our data obtained for the area with coordinates 57°S — 158°W in 1985, the abundance of bacteria in the 0-200 m layer varied from 155 to $612 \cdot 10^3$ cells/mL, the mean volume of bacteria was 0.074 μm^3, and the biomass was 5.94 mg/m^3 (Sazhin and Kopylov 1988).

Rather high values of abundance and biomass of the bacterioplankton obtained in this study evidence that even in the most southern part of open regions of Antarctic zone of the Pacific the microorganisms play important role in the recycling of nutrients, i.e. a considerable flux of matter and energy passes through the microplanktonic community. Indeed, the high concentration of bacteria does not directly reflect the intense functioning of «microbial loop» in the water area studied. Nevertheless, the present values of bacterioplankton abundance are comparable to the data obtained for highly productive temperate waters including a rich subantarctic zone of the Pacific (Sazhin and Kopylov 1988). The leading role of microplanktonic community in the food web of studied waters of the Pacific sector of the Antarctica is also confirmed by our data on composition and amount of phytoplankton. Small microplanktonic forms prevailed in numbers and in biomass among algae at practically all stations of the transect.

In the ACC waters during the period of studies, zones with the lowest values of bacteria numbers and biomass corresponded to the zones with the coldest water for the given station and the given layer. In summer warmed layer, lower concentration of microorganisms was recorded at st. 694, 708, and 720, as well as in the waters of transition zone at st. 733 (Figs. 2 and 3). As an addition to those stations, station 736 can also be regarded where the abundance of bacteria was only insignificantly lower than at neighboring stations while the biomass was much the same. The water temperature in the layers with decreased microorganism concentration varied from +0.3°C to +0.7°C. At stations 703 and 714 (with higher bacterioplankton concentration) in the summer warmed layer, the water temperature fluctuated from +0.7°C to +0.86°C. Such a correlation was not observed in waters of the Ross circulation, and the relative richness of that zone (summer warmed and cold residual layers) can be explained by more stable hydrophysical conditions of that region.

In the most part of the transect in both ACC and Ross circulation waters, layers with the highest gradients of mean volumes, biomass, and, to a lesser extent, abundance of bacteria were associated with 0° isotherm at the lower border of cold residual layer (approximately 100 m) (Figs. 2 and 3).

A complete agreement between hydrophysical data and microbiological indices was clearly followed only in the transect portion from st. 767 towards the Pennell Coast where intervals between stations of biological work were considerably smaller than in the main part of the transect (Fig. 1). Isolines of bacterium concentrations in this area generally followed the isolines of temperature, salinity, and density and were characterized by a deepening just near the shelf. The 120-220 m layer at st. 771 greatly depleted in bacteria ($80\text{-}120 \cdot 10^3$ cells/mL, or 4-5 mg/m^3) was formed by «young» deep waters occurring rather close to the surface at this point.

Simultaneous consideration of hydrophysical characteristics and bacterioplankton distribution in the transect allows to distinguish borders of main habitats of the microplankton communities in this part of the South Ocean. The data on abundance and biomass of bacteria show that over the entire water area studied, the microplankton complexes are vertically restricted by waters of summer warmed and cold residual layers. In deeper waters, the concentration of bacterioplankton and, judging from our data, the abundance of small prototrophic and heterotrophic forms decreases to minimum values. Two large habitats are clearly defined horizontally: the waters of the ACC southern periphery and the waters of the Ross circulation separated from the former by a transition zone.

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Бактериопланктон поверхностной зоны Тихого океана

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РЕЗЮМЕ. Основываясь на данных по концентрации бактериопланктона и гидрофизических характеристиках в поверхностной зоне разреза по 67° ю.ш. в тихоокеанском секторе Антарктики, определяются границы основных биотопов микропланктонных организмов в этой части Южного океана. Обсуждается роль бактерий и «микробной петли» в функционировании пелагических комплексов исследуемых вод.Материал был собран с 22 февраля по 30 марта 1992 г. на 21 станции в слое 0-200 м. В период работ численность бактериопланктона колебалась от 68 тыс.кл./мл до 634 тыс.кл./мл, средний объем бактериальных клеток варьировал в пределах 0.042 - 0.170 мкм^3, биомасса менялась от 9 мг/м^3 до 82 мг/м^3. Данные по численности и биомассе бактерий показывают, что на всей исследуемой акватории по вертикали микропланктонные комплексы ограничены водами слоев летнего прогрева и холодного остаточного. Наибольший градиент средних объемов клеток и, в меньшей степени, численности бактерий был связан с изотермой 0° на нижней границе холодного остаточного слоя. По горизонтали четко выделяются два больших биотопа: воды южной периферии Антарктического Циркумполярного Течения и отделенные от них транзитной зоной, воды круговорота Росса. Относительно высокие значения численности и биомассы бактериопланктона свидетельствуют, что и в самой южной части открытых районов антарктической зоны Южного океана микроорганизмы осуществляют интенсивный рециклинг биогенных элементов, то есть значительный поток вещества и энергии проходит через микропланктонное сообщество.